

Using Los Alamos Geosynchronous Energetic Particle Data in Support of the Cluster Mission

G. D. Reeves, R. D. Belian, T. C. Cayton, M. G. Henderson, R. A. Christensen, P. S. McLachlan, and J. C. Ingraham

Los Alamos National Laboratory, Mail Stop D436, Los Alamos, NM 87545, USA, reeves@lanl.gov

Abstract. A prime objective of the International Solar Terrestrial Physics (ISTP) program is to synthesize "the big picture" of magnetospheric processes. Los Alamos geosynchronous energetic particle data can be used along with other ISTP and ground-based data to put Cluster observations into a more global context. This paper presents an overview of a database of Los Alamos geosynchronous energetic particle data and the tools available to access and analyze those data. Los Alamos geosynchronous energetic particle measurements began in 1976 and will continue throughout the Cluster mission. The data are taken in real time and are put on-line for public access within 24-hours. Both digital data and summary plots are available daily through a World Wide Web interface and through a text-based guest account. Typically data are available simultaneously from three geosynchronous satellites. Two generations of instruments have flown – the Charged Particle Analyzer (CPA) and Synchronous Orbit Particle Analyzer (SOPA). Both instruments measure electrons and ions with energies from tens of keV to tens of MeV. The data which have been made available on-line consist of 1-spin (approximately 10-second) averages or 1-minute (approximately 6-spin) averages. This paper includes a brief description of the data holdings, instructions for accessing digital data and summary plots, and other reference material related to the data.

Introduction

Los Alamos geosynchronous energetic particle data can provide a broader context for interpreting Cluster observations. Geosynchronous satellites are well-positioned to measure a variety of important magnetospheric processes. Geosynchronous orbit lies near the outer edge of the radiation belts but still within the region of stable trapping for electrons and ions with energies greater than several tens of keV. That is the source region for injection of ions into the ring current and for the inward radial diffusion of both electrons and ions into the radiation belts. Geosynchronous orbit is also near the inner edge of the thermal plasma sheet. It is now generally recognized that the inner edge of the plasma sheet plays an important role in substorm dynamics. All of the commonly-used magnetospheric magnetic field models predict that the magnetic foot-point of geosynchronous orbit lies in the auroral zone [Reeves *et al.*, 1996] and dispersionless injections of electrons and ions during substorms are most commonly observed from geosynchronous platforms.

Geosynchronous particle data can be used to investigate more than storms and substorms too. The location of magnetospheric boundaries such as the energetic particle trapping boundaries, the plasmapause, the plasma trough, and the plasma sheet can all be identified

at geosynchronous orbit [e.g. *McComas et al.*, 1993]. Under conditions of strong solar wind forcing geosynchronous spacecraft can even find themselves in the open field-line region of the lobes or outside the magnetopause in the magnetosheath. Although they have been underutilized for the purpose, particle data can provide important information about plasma waves including Pi2, Pc5, and others. Geosynchronous satellites also measure relativistic electron enhancements, which produce deep dielectric charging, and solar energetic particle events, which produce single event upsets. Both of these processes are critical for space weather applications.

Because of the importance of geosynchronous orbit, both as a prime location for satellites and as an interesting region of the magnetosphere, Los Alamos National Laboratory has flown a series of energetic particle detectors on geosynchronous satellites beginning in 1976 and continuing through the present. This paper describes those data and an on-going project to make the data available on-line as digital data, as summary plots, and as data synthesis products. The primary access to data, plots, and other information is currently the "World Wide Web"—a graphical interface to the internet. One can view this paper as a summary of what is available on "the Web" and a set of instructions for accessing more detailed information.

The Data

Geosynchronous orbit is a circular orbit located at a geocentric distance of approximately $6.6 R_E$ (42,000 km) where the orbital period is approximately 24-hours. In that orbit a spacecraft will stay “fixed” above a particular geographic longitude. A spacecraft at the geographic equator, though, can be up to $\pm 11^\circ$ off the magnetic equator due to the tip of the earth’s dipole with respect to its spin axis. Thus geosynchronous satellites at different geographic longitudes will be at slightly different magnetic latitudes and therefore slightly different L-shells. In addition the asymmetries and temporal variation of the earth’s magnetic field can also make a geosynchronous satellite sample different magnetic L-shells. However, the variation in L is typically quite small and, compared to an orbit like Cluster’s, geosynchronous satellites are essentially fixed at $L=6.6$.

Combined, the data from three or more satellites at a fixed L-shell provide excellent temporal and Local Time coverage. There is nearly always a satellite within 4 hours of local midnight. At the same time there is nearly always another satellite within 4 hours of local noon. Thus there is nearly continuous monitoring of both of these important regions. Furthermore, with multiple satellites at the same L-shell one can distinguish global processes such as the compression associated with sudden impulses from local processes such as substorm injections in the magnetotail. In addition multiple satellites can be used to measure drifting populations of particles at several points on a drift orbit. For example a dispersionless substorm injection and its dispersed “echo” can often be observed with two or more satellites.

The geosynchronous satellites which carry Los Alamos energetic particle instruments are referred to by their unimaginative and unromantic International Satellite Designator Numbers (ISDN). An example is satellite 1989-046. The first four digits refer to the year of launch. A given satellite such as 1989-046 might be operated at a single geographic longitude for its entire lifetime or it might be moved to a different longitude according to the needs of the mission. In general though, one satellite has operated near 70°W . Longitude, one has operated between 130° and 170°E . Longitude, and one has operated between 30° and 70°E . Longitude. Other longitudes have been covered at various times and for various amounts of time [[ep_locations.html](#)]. As of March 1996 the three principle satellites providing data were 1990-095 at 36°W ., 1991-080 at 69°E ., and 1994-084 at 103°E .

Los Alamos has flown two generations of energetic particle detectors at geosynchronous orbit. The Charged Particle Analyzer (CPA) instrument was flown on satellites from 1976 to 1987 and one or more CPA-equipped satellites operated through 1995. The Synchronous Orbit Particle Analyzer (SOPA) was flown on satellites beginning in 1989. Four SOPA-equipped satellites have been launched so far. Typically data are received from

three or four satellites simultaneously. Nominal data coverage is 24-hours per day but data gaps do exist. Frequently a data gap on one satellite is due to switching ground receivers from that satellite to another satellite in the constellation. (See Figure 1.) Between 1989 and 1995 data are typically available from both CPA-equipped satellites and SOPA-equipped satellites. Beginning in 1996 data have been available from SOPA-equipped satellites only.

Although the CPA and SOPA instruments are similar there are some differences. CPA measures electrons from 30 keV to 2 MeV in 12 energy channels. It measures protons from approximately 75 keV to approximately 200 MeV in 26 energy channels. Six “low energy” electron channels are measured with five telescopes at angles of 0° , $\pm 30^\circ$, and $\pm 60^\circ$ from the spin plane while the remaining measurements are made with single-look direction telescopes mounted at 0° with respect to the spin plane (referred to as the “belly band”). More detailed information on the CPA can be found in *Higbie et al.*, [1978] or in the LANL Energetic Particle bibliography [[ep_publications.html](#)].

The SOPA instrument measures electrons from 50 keV to greater than 1.5 MeV in 10 energy channels and protons from 50 keV to 50 MeV in 12 channels. In addition there are ten channels for heavy ions including alpha particles, Carbon, Nitrogen, Oxygen, and others. (Heavy ion data are not yet available on line and will not be discussed further in this paper.) Protons and electrons are measured together using three telescopes mounted at 0° , 30° , and -60° with respect to the spin plane (belly band). More detailed information on the SOPA can be found in *Belian et al.*, [1992] or in the LANL Energetic Particle bibliography [[ep_publications.html](#)].

Spacecraft carrying both generations of instruments (CPA and SOPA) are actively controlled such that the spin axis of the satellite points continuously toward the center of the earth. Therefore the nominal dipole magnetic field direction is approximately perpendicular to the spin axis. In that configuration complete pitch angle coverage is obtained for all electrons and ions each spin of the spacecraft (about 10.24 seconds). When the field becomes inclined and is no longer perpendicular to the spin axis excellent pitch angle coverage is still obtained for all SOPA channels (from 3 telescopes) and from the six “low energy” CPA channels (from 5 telescopes) while the other CPA measurements are limited in pitch angle according to the inclination of the field. This limitation should be remembered when analyzing spin-averaged data.

In addition, satellites carrying SOPAs also carry the Energy Spectrometer for Particles (ESP) instrument [*Meier et al.*, 1996] which measures electrons from 0.7 to 26 MeV in 6 channels and protons from 11 to greater than 20 MeV in three channels. Those data are not yet included in our on-line database and will not be discussed further in this publication.

On-Line Access

Digital data have been stored on-line using a SUN workstation and 12 GB of hard disk storage. The name of the workstation is `leadbelly.lanl.gov` and its internet node number is 128.165.207.108. Leadbelly is named after the great blues pioneer Huddie Ledbetter, better known as Leadbelly [<http://leadbelly.lanl.gov/leadbelly.html>]

A single data file is stored for each satellite for each day. By convention files are named with the date (Universal Time) and International Satellite Designator Number. The date is in YYMMDD format so a file for November 2, 1991 for satellite 1989-046 will be called 911102_1989-046. A file extension may be added to indicate how the data were processed. For example, 911102_1989046.flux.sum. The data are stored as ASCII text files which have then been compressed with the `gzip` utility. Each file includes ephemeris information. The first column is universal time (in decimal hours), followed by geographic latitude (-90° to $+90^\circ$), geographic longitude (-180° to $+180^\circ$), geocentric radius (in R_E), and count rates (counts/second) for each energy channel. The data may be processed to extract only certain energy channels, to convert count rates to flux, or to sum sets of energy channels.

Two sets of data files are archived. From 1989 to the present the raw telemetry data were stored on optical platters. Those data have been reprocessed to produce 1-spin (≈ 10 -second) averages. From 1979 to 1989 1-minute averages were stored along with the raw telemetry data on magnetic tape. Those data have been reprocessed to produce 1-minute average data files in the same format as the 10-second data files. Over 6,000 of the original magnetic tapes are being reprocessed to produce 10-second averages to replace the 1-minute averages and to fill in 1976 to 1979 when no averages were archived. Currently 10-second averages have been produced for 1986 (the PROMIS period which includes coverage by the Viking auroral imager) and for 1979 (which includes ISEE 1 and 2 tail coverage) in addition to all the data from 1989 onward.

Currently raw telemetry files are processed daily to produce files of 10-second averages. Files and summary plots for the previous day (defined by UT) are placed on the data server at approximately 20:00 UT each day. Therefore data and plots should be available to Cluster investigators in an extremely timely manner. In addition for special spacecraft operations it is now possible to arrange for real-time display of the data. Real-time data displays can be updated as frequently as every 10-seconds.

The Energetic Particle Home Page [lanl.ep.html]

All of the data and summary plots described here are available electronically over the internet. As the primary means for accessing those products we have chosen to use the graphical interface and server protocol

known as the World Wide Web (or simply the Web).. The web server is also known as `leadbelly.lanl.gov` and the Universal Resource Locator (URL) is <http://leadbelly.lanl.gov/>.

The Los Alamos Energetic Particle "Home Page" is located at lanl.ep.html. (If a full URL is not given the prefix http://leadbelly.lanl.gov/lanl.ep_data/ should be assumed. E.g. http://leadbelly.lanl.gov/lanl.ep_data/lanl.ep.html). The LANL EP Home Page is a common point of reference for finding other pages. From there the user can (1) request digital data as described below, (2) access summary plots of the data—also described below, or (3) obtain supplemental information about the data or about related topics. Supplemental information includes information about the satellites, the CPA and SOPA instruments, and about the database itself. It also includes information about the energetic particle team, a bibliography of publications which use the LANL energetic particle data, and on-line collaborative projects.

Requesting Digital Data [ep_request.html]

Digital data are stored as compressed text files with ephemeris and count rates. Typically the data need to be processed before they are useful to the average user. Therefore we have established a request system. The first part of the request system is a World Wide Web form [ep_request.html]. To request data you specify information such as your name and e-mail, the date and times you want data for, what satellites, what energy channels, the time resolution required, and whether you want flux units or count rates. The request form generates an input file to a program that actually processes the data. Processed data are put in a unique directory for each request. One data file is produced for each satellite and each day requested. The data are provided as text files (not compressed) and include ephemeris as well as fluxes or count rates. The requester is notified by e-mail when the data are ready and can download the data by anonymous FTP or through a Web interface.

As discussed above the raw telemetry files are processed into 10-s averages on a daily basis. Therefore data are typically available within about 24 hours of when they were acquired. The system is currently optimized to request as little as a few minutes of data or as much as several weeks worth of data. Long-term surveys (months or years worth of data) currently require too much processing power for the on-line system. In the future, hourly and daily averages will be produced and put on-line for long-term studies.

Viewing Summary Plots [summary_plot_chose.html]

While access to digital data is often essential for a study or as input to a model, it is often more convenient to quickly view a summary plot of the data. Summary plots can be useful to determine what satellites were providing data at a particular time, where they were located, and whether something interesting was happen-

ing. A quick check of a summary plot can let you know whether it is even worth while requesting digital data.

One key to making summary plots useful is that it must be quick and easy to view them, to find the date you are interested in, and to page through plots as one would with hard copy. For this to be practical, the plots are pre-generated and saved as GIF images which are viewable by a web browser. Currently only one type of summary plot has been produced. An example is shown in Figure 1. These summary plots highlight substorm injection activity. The plot shows 30-300 keV (for CPA) or 50-315 keV (for SOPA) electron fluxes over 24-hours of universal time. The plot has stacked panels with one panel for each satellite. The time at which the satellite passed midnight is indicated with a vertical bar. Substorm injections show up most clearly in the electron fluxes when the satellite is near midnight or in the dawn sector (e.g. in Figure 1, ≈ 1530 UT, for satellite 1989-046). Drifting injections of electrons can be seen at other local times (e.g. in Figure 1, ≈ 1530 UT, for satellites 1987-097 and 1990-095).

Using buttons the user can page through plots, forwards or backwards, from one day to another or by using a form [summary_plot_choose.html] the user can chose the year, month, and day of interest. Additional information and links to the other Los Alamos energetic particle web pages are also provided.

As with the digital data summary plots are produced on a daily basis and are generally available 24-hours after the data were acquired. Other useful summary plots are envisioned. Summary plots of “low energy” protons in a format similar to those already available for electrons will be available in the near future. For higher energies monthly and/or yearly summary plots will be made available for relativistic electron enhancements (e.g. >2 MeV) and for solar energetic particle events (e.g. >10 MeV). Several data synthesis products are being developed. A Geosynchronous Electron Flux (GEF) index has been developed and is available for testing. The GEF index is a single-variable time series of 50-300 keV electrons from whatever satellite is closest to midnight. This index is useful for comparison with other indices such as AE or Dst and for more complex analyses that are not amenable to input from multiple energy channels and from multiple satellites. A complimentary Global Geosynchronous Synthesis model which interpolates between satellites for full local time coverage is also being developed.

Although summary plots are not yet available for all energies of protons and electrons the complete data are available in digital format. Therefore, individual users can always develop their own displays. In addition if the Cluster community feels that a particular display would be particularly valuable for interpreting Cluster data it should be possible to produce those displays on a routine basis and to make them available on-line in the same manner.

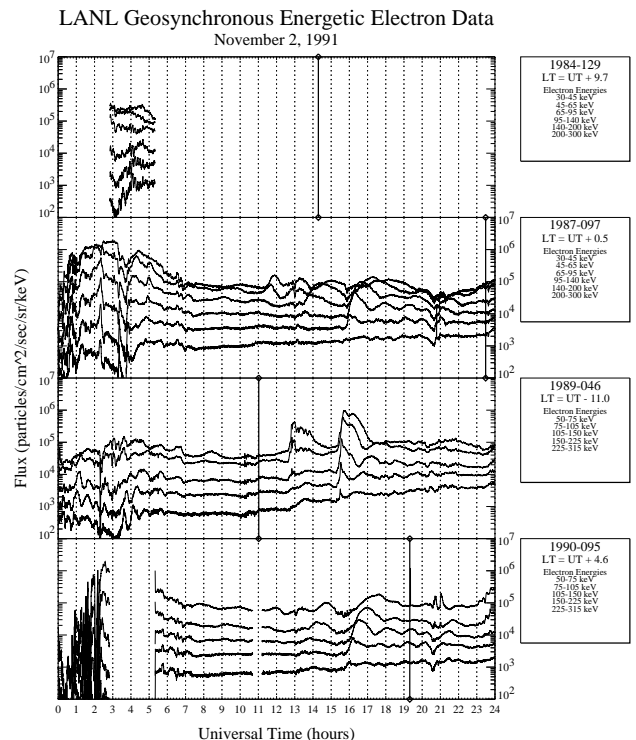


Figure 1. A typical electron summary plot. These plots are viewable as GIF images with any Web browser. There is one plot for each day from 1979 to the present. Additional hypertext buttons allow the user to page through plots, to select other dates, or to get additional information about the plots and the data.

Conclusions

The Cluster mission offers a unique new opportunity to understand the magnetosphere. The potential of Cluster can be further enhanced by making use of complimentary data sets. The Los Alamos energetic particle data set is one of those which is likely to be useful for providing a broad context for interpreting Cluster data and ultimately for understanding magnetospheric processes.

To be useful, though, the data must be easily accessible. Towards that end the Los Alamos energetic particle team has developed an on-line database of energetic particle data from geosynchronous orbit which is accessible over the internet. Digital data can be requested and downloaded on-line. Summary plots can be also be viewed on-line. Both digital data and summary plots are updated daily and are therefore available in a very timely manner. In addition much of the information needed to properly interpret the data can also be found on-line. Only a portion of that information could be included in this brief introduction to the data system. We also note that, while much of the data system can be considered complete, many more useful features will be added as they are developed. Readers are encouraged to

browse the database and web pages for themselves and to provide us with comments and suggestions which will improve its utility for the Cluster mission.

References

- Note:** In this paper if a full URL is not given the prefix http://leadbelly.lanl.gov/lanl_ep_data/ should be assumed. For example the full URL for [lanl_ep.html](http://leadbelly.lanl.gov/lanl_ep_data/lanl_ep.html) is http://leadbelly.lanl.gov/lanl_ep_data/lanl_ep.html.
- Belian, R. D., G. R. Gisler, T. Cayton, and R. Christensen, High Z energetic particles at geosynchronous orbit during the great solar proton event of October, 1989., *J. Geophys. Res.*, *97*, 16,897, 1992.
- Higbie, P. R., R. D. Belian, and D. N. Baker, High-resolution energetic particle measurements at 6.6 R_E 1, Electron micropulsations, *J. Geophys. Res.*, *83*, 4851, 1978.
- McComas, D. J., S. J. Bame, B. L. Barraclough, J. R. Donart, R. C. Elphic, J. T. Gosling, M. B. Moldwin, K. R. Moore, and M. F. Thomsen, Magnetospheric plasma analyzer (MPA): Initial three-spacecraft observations from geosynchronous orbit, *J. Geophys. Res.*, *98*, 13,453, 1993.
- Meier, M. M., R. D. Belian, T. E. Cayton, R. A. Christensen, B. Garcia, K. M. Grace, J. C. Ingraham, J. G. Laros, and G. D. Reeves, The energy spectrometer for particles (ESP): Instrument description and orbital performance, *Proc. Taos Wkshp. on Earths Trapped Particles*, Taos, NM, in press, 1996.
- Reeves, G. D., L. A. Weiss, M. F. Thomsen, and D. J. McComas, A Quantitative Test of Different Magnetic Field Models Using Conjunctions Between DMSP and Geosynchronous Orbit, *Proc. Workshop on Radiation Belt Models*, Brussels, Belgium, in press, 1996.

R. D. Belian, T. C. Cayton, R. A. Christensen, M. G. Henderson, J. C. Ingraham, P. S. McLachlan, and G. D. Reeves, Los Alamos National Laboratory, Mail Stop D436, Los Alamos, NM 87545, USA, reeves@lanl.gov